

## Technical Innovations and Notes

# A DUAL COMPUTED TOMOGRAPHY LINEAR ACCELERATOR UNIT FOR STEREOTACTIC RADIATION THERAPY: A NEW APPROACH WITHOUT CRANIALLY FIXATED STEREOTACTIC FRAMES

MINORU UEMATSU, M.D., TOSHIHARU FUKUI, R.T.T., AKIRA SHIODA, R.T.T.,  
HIDEYUKI TOKUMITSU, R.T.T., KENJI TAKAI, M.D., TADAHARU KOJIMA, B.S.,  
YOSHIKO ASAI, B.S. AND SHOICHI KUSANO, M.D.

Department of Radiology, Division of Radiation Oncology, National Defense Medical College, Saitama, Japan

**Purpose:** To perform stereotactic radiation therapy (SRT) without cranially fixated stereotactic frames, we developed a dual computed tomography (CT) linear accelerator (linac) treatment unit.

**Methods and Materials:** This unit is composed of a linac, CT, and motorized table. The linac and CT are set up at opposite ends of the table, which is suitable for both machines. The gantry axis of the linac is coaxial with that of the CT scanner. Thus, the center of the target detected with the CT can be matched easily with the gantry axis of the linac by rotating the table. Positioning is confirmed with the CT for each treatment session. Positioning and treatment errors with this unit were examined by phantom studies. Between August and December 1994, 8 patients with 11 lesions of primary or metastatic brain tumors received SRT with this unit. All lesions were treated with 24 Gy in three fractions to 30 Gy in 10 fractions to the 80% isodose line, with or without conventional external beam radiation therapy.

**Results:** Phantom studies revealed that treatment errors with this unit were within 1 mm after careful positioning. The position was easily maintained using two tiny metallic balls as vertical and horizontal marks. Motion of patients was negligible using a conventional heat-flexible head mold and dental impression. The overall time for a multiple noncoplanar arcs treatment for a single isocenter was less than 1 h on the initial treatment day and usually less than 20 min on subsequent days. Treatment was outpatient-based and well tolerated with no acute toxicities. Satisfactory responses have been documented.

**Conclusion:** Using this treatment unit, multiple fractionated SRT is performed easily and precisely without cranially fixated stereotactic frames.

Radiation therapy, Stereotactic, Fractionated, Treatment unit, Linear accelerator, Computed tomography.

## INTRODUCTION

Stereotactic radiation therapy (SRT) or stereotactic radiosurgery (SRS) is usually performed with a cranially fixated stereotactic frame to make each treatment highly precise (6, 7, 11). However, the use of such frames is usually uncomfortable for patients and sometimes may be troublesome, especially when multiple-fractionated treatment is planned. Recently, noninvasive relocatable frames have been developed (4, 5), although positioning errors may be slightly larger than those with invasive frames (4). To perform SRT or SRS easily and precisely without a cranially fixated stereotactic frame, we developed a dual computed tomography (CT) linear accelerator (linac) treatment unit.

## METHODS AND MATERIALS

This unit is composed of a linac,<sup>1</sup> CT,<sup>2</sup> and motorized table.<sup>3</sup> The linac and CT are set up at opposite ends of the table, which is suitable for both machines (Fig. 1). The gantry axis of the linac is coaxial with that of the CT scanner. The center of the target volume, which is detected and planned by the CT, can be matched easily with the gantry axis of the linac, simply by rotating the table around the C2 axis (Fig. 1). To make several noncoplanar planes, the table is rotated around the C1 axis (Fig. 1).

Positioning and treatment errors with this unit were examined by phantom studies (Figs. 2-4). A metallic target (5 mm in diameter) was put in the phantom and

Reprint requests to: Minoru Uematsu, M.D., Department of Radiology, Division of Radiation Oncology, National Defense Medical College, 3-2, Namiki, Tokorozawa, Saitama, 359, Japan.

Accepted for publication 6 December 1995.

<sup>1</sup> MEVATRON 77, DX 67, Siemens, NJ, USA.

<sup>2</sup> TCT-500S, Toshiba, Tokyo, Japan.

<sup>3</sup> CLT-01A modified, Toshiba, Tokyo, Japan.

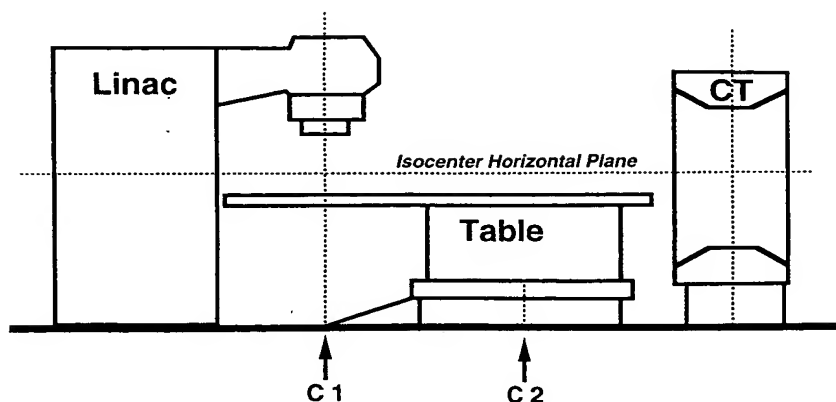


Fig. 1. Diagram of the dual CT-linac treatment unit. The table has two rotation axes; C1 is for isocentric rotation to make noncoplanar arcs and C2 is for rotation between CT and linac. The gantry axis of the linac is coaxial with that of the CT scanner.

was roughly checked by CT scanner with slice thickness of 5 mm and slice interval of 5 mm. After roughly detecting the target, the final verification of the center of the target volume was performed with slice thickness of 2 mm and slice interval of 1 mm, and the center was decided. To verify and maintain the center, two tiny metallic balls (0.4 mm in diameter) were attached to the phantom as the vertical and horizontal marks, using the laser pointer indicating the gantry axis of the CT. Then,

the same slice was scanned (Fig. 2). In general, detecting 0.4 mm materials clearly on the CT image with slice thickness of 2 mm needs a quite precise setup. Thus, to verify the accuracy of our positioning technique, 1 and 2 mm cranial and 1 and 2 mm caudal CT slices from the center slice were checked (Fig. 3). The differences in imaging the tiny metallic balls on the each slice were presented. Following the positioning and targeting as in Fig. 2, the table was rotated around the C2 axis, to match

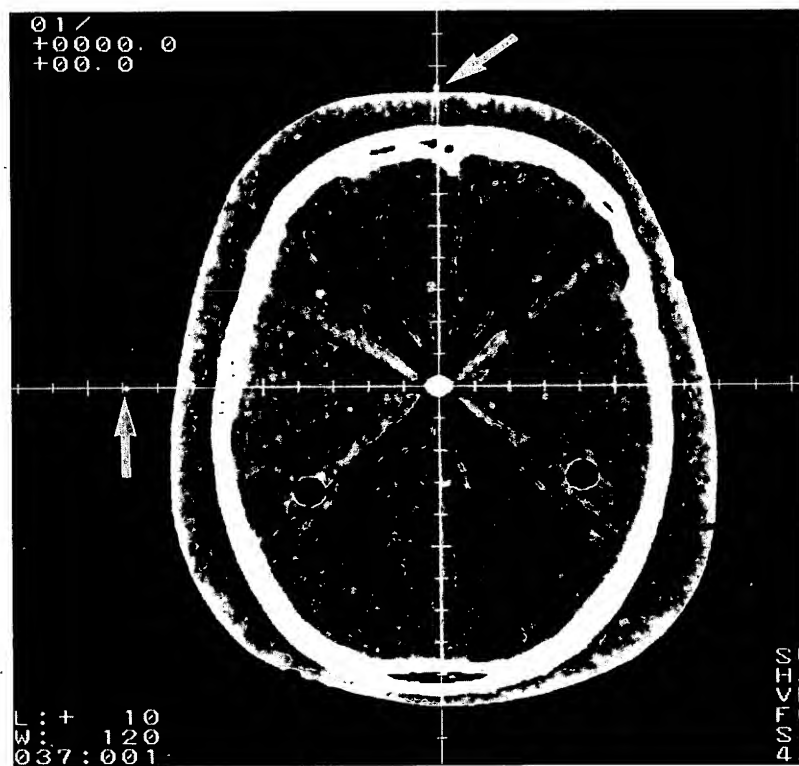


Fig. 2. The final positioning in the phantom examination.

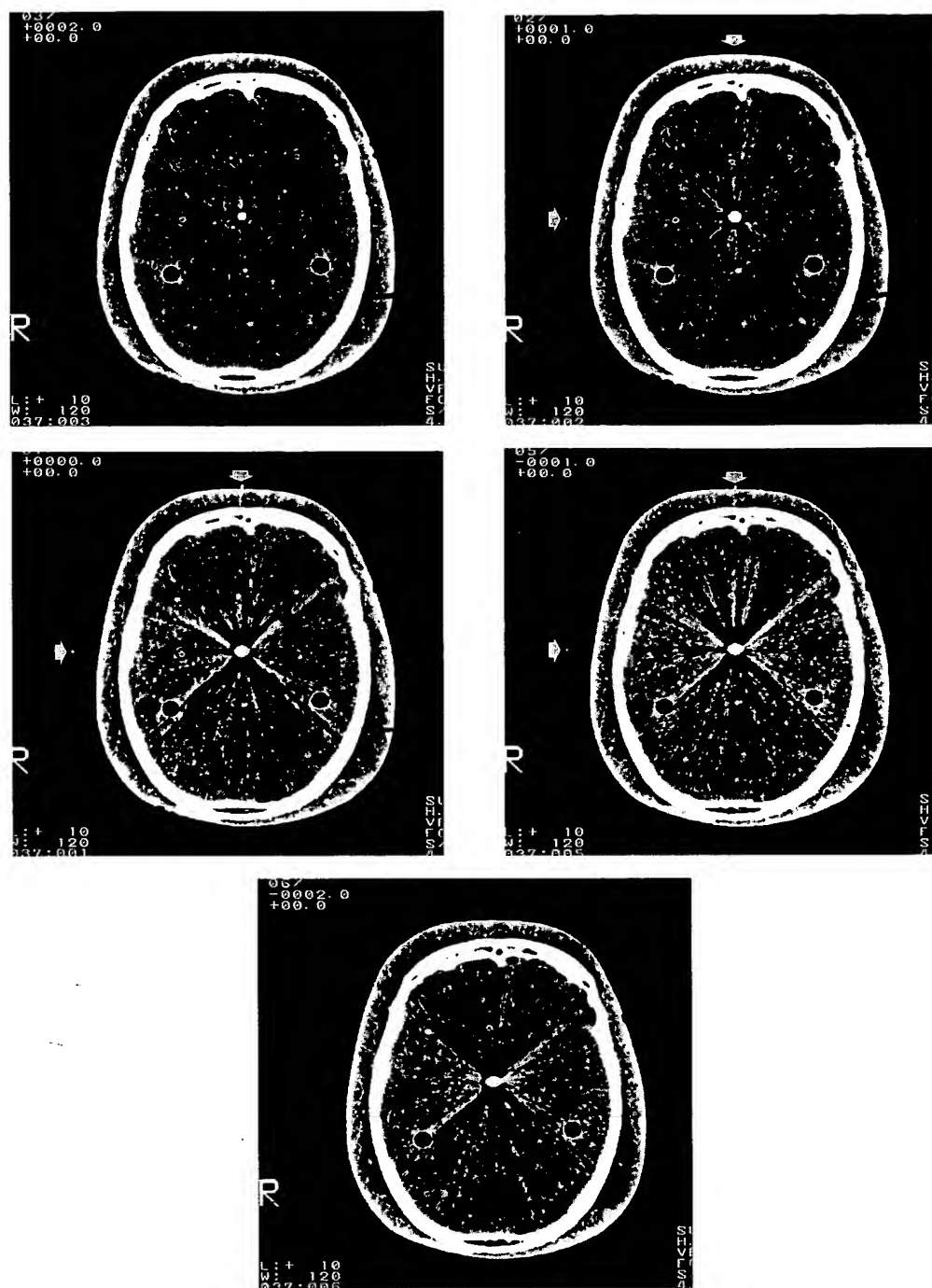


Fig. 3. The phantom examinations. (a) 2 mm cranial from the center; (b) 1 mm cranial from the center; (c) the center of the target; (d) 1 mm caudal from the center; and (e) 2 mm caudal from the center. Two tiny metallic balls are clearly seen in (c), smaller in (b) and (d), and not seen in (a) and (e).

the center of the target volume with the gantry axis of the linac, and portal films were performed with collimated beam irradiation using a circular aperture (Fig. 4).

Between August and December 1994, 8 patients with 11 lesions of primary or metastatic brain tumors were treated with this unit. All patients received fractionated

SRT with 24 Gy per 3 fractions to 30 Gy per 10 fractions to the 80% isodose line, usually using six noncoplanar arcs, with or without conventional external beam radiation therapy. On the initial treatment day of SRT, (a) a conventional heat-flexible head mold and dental impression (13) were made for immobilization of individual patients on the

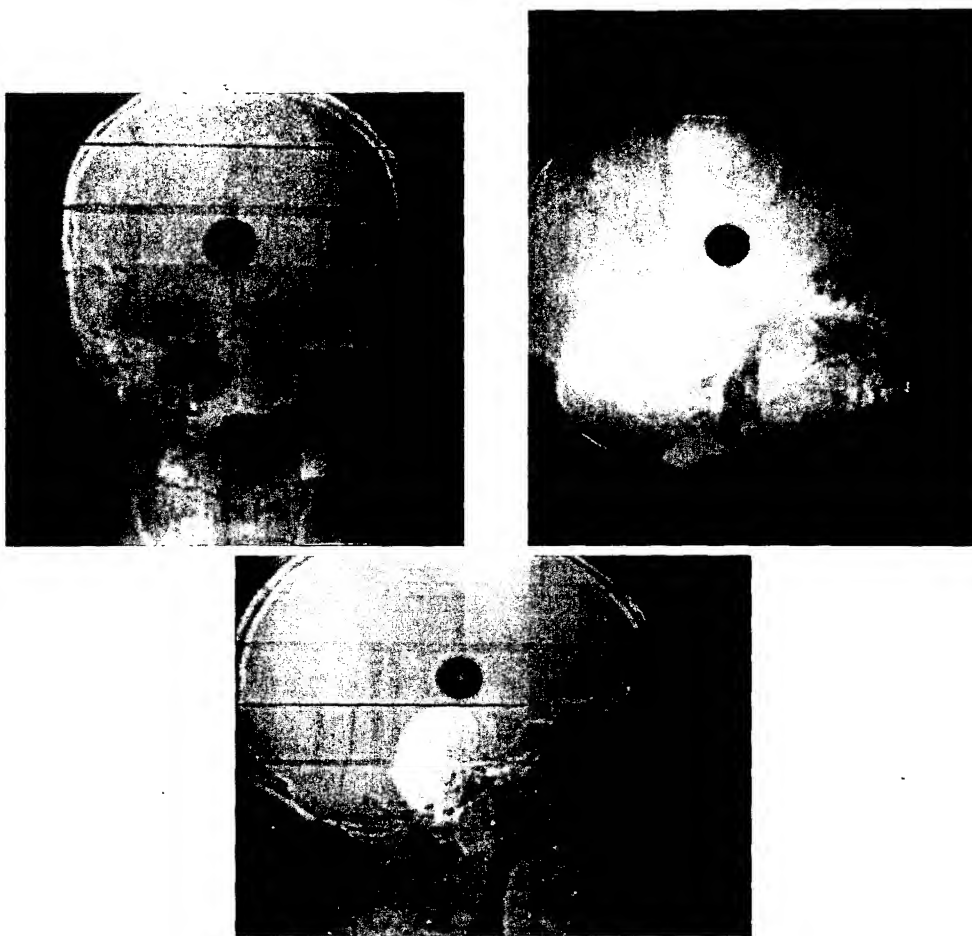


Fig. 4. Portal films in three typical directions following the positioning in Fig. 2. The errors are very small after the rotation of the table and the gantry rotation of the linac.

table; (b) the patient with the mold was examined by CT; (c) the center of the target detected by the CT was positioned at the gantry axis of the CT; (d) two tiny metallic balls were attached to the mold as the vertical and horizontal marks (Fig. 5); (e) the table was rotated, to match the center of target with the gantry axis of the linac; and (f) treatment was performed usually with one or two of the six planned noncoplanar arcs. On subsequent days, (a) the patient with mold was set up on the table using two tiny metallic balls; (b) a scan was performed to confirm that the position of the center of the target was at the gantry axis of the CT; and (c) if the position was acceptable, the treatment was performed; or if the position was not acceptable, it was repositioned by CT and the tiny metallic balls were also repositioned, and treatment was performed. Position was thereby confirmed with CT for every treatment session, and for contrast enhancing lesions, iodine contrast materials were used for each positioning session.

### RESULTS

Phantom studies confirmed the accuracy of positioning and treatment with this unit. Five CT scan images follow-

ing the attachment of the tiny metallic balls are presented in Fig. 3. The central plane is Fig. 3c, in which two tiny metallic balls are clearly seen (the same slice as Fig. 2). In the slices 1 mm cranial and caudal from the central slice (Fig. 3b and 3d), the balls are seen but smaller. In the slices 2 mm cranial and caudal (Fig. 3a and 3e), the balls are not seen. Thus, to see both of the two tiny metallic balls clearly on the CT image is a highly precise way to confirm not only the vertical and horizontal positionings but also the craniocaudal one. After targeting (Fig. 2), the table was rotated, and then, portal films of three typical directions with collimated beam were examined (Fig. 4). In the portal films, errors with rotating the table between the CT and linac were within 0.5 mm and errors with the gantry rotation of the linac were also within 0.5 mm. Thus, overall possible treatment errors using this unit seem to be within 1 mm after careful positioning.

Motion of patients was negligible using a conventional heat-flexible head mold and dental impression. In five of the eight patients who were set up with a mold and dental impression, repositioning by CT was not necessary on

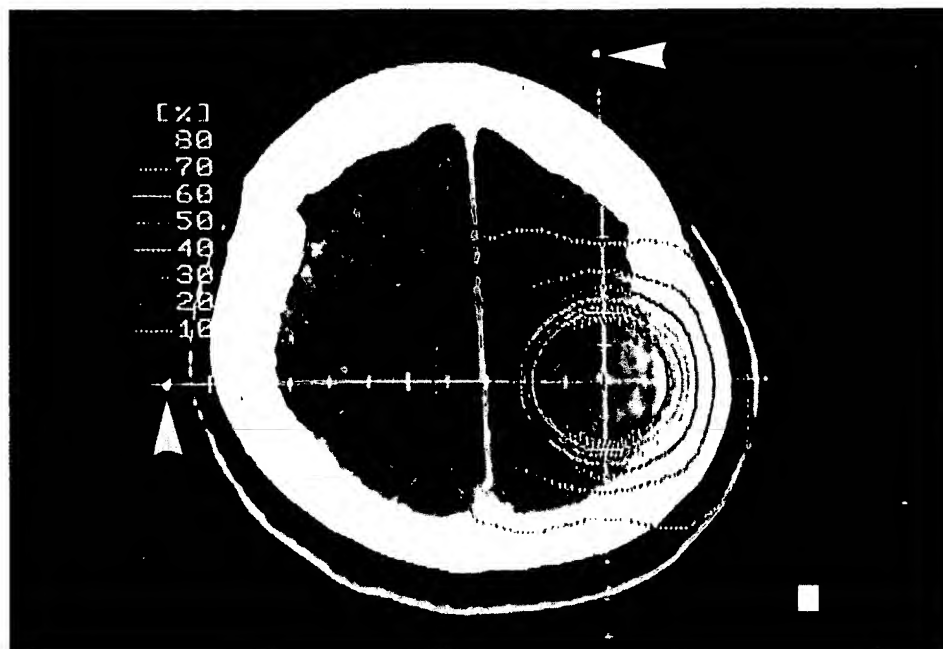


Fig. 5. Targeting of brain metastasis of lung adenocarcinoma. Two tiny balls are clearly seen, suggesting good positioning. To the 80% isodose line, 27 Gy per 3 fractions over 5 days were given, with conventional whole brain irradiation of 30 Gy per 10 fractions over 2 weeks.

days subsequent to the initial session. Three patients who were set up with a mold but without a dental impression required repositioning due to minor errors. Treatment time with this unit was short. On the initial treatment day,

the overall time for SRT for a single isocenter was less than 1 h including a making of a mold, CT positioning, and treatment of one or two arcs. On subsequent days, it took only 15 min or less when repositioning was not

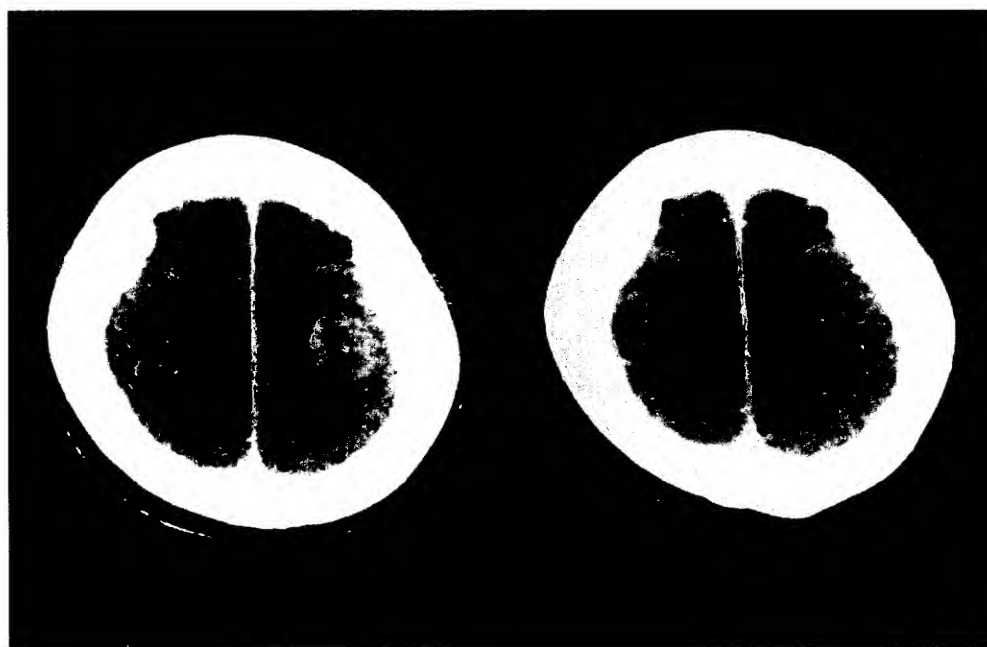


Fig. 6. The same patient as Fig. 5. Left: prior to SRT; the enhancing lesion is 2.5 cm in diameter. Right: following SRT; the lesion is not visible.

necessary, and it took about 20 min if the patient was repositioned. Treatments were outpatient-based and well tolerated with no acute toxicities or adverse effects. Satisfactory responses have been documented in several patients (Fig. 6).

## DISCUSSION

SRT or SRS are excellent treatments for well-circumscribed small intracranial lesions (9, 11). Although SRS is more suitable for benign lesions, SRT, which applies multiple fractionated treatments, is preferable for malignant tumors (2, 8, 9). However, SRT with multiple fractionation is very uncomfortable for patients, because invasive cranially fixated frames are used (4). To perform SRT without cranially fixated frames, we developed a dual CT-linac unit. This unit permitted simple and precise SRT only with a heat-flexible head mold and dental im-

pression. Phantom studies confirmed the accuracy of the positioning and treatment with this unit. The two tiny metallic balls were effective to verify and maintain the position not only in the vertical and horizontal directions but also the craniocaudal one. Treatment time including all setups was short enough to maintain patients' comfort, and improved the throughput similar to conventional radiation therapy.

Recent advances in stereotactic or three dimensional radiation therapy are mainly due to improvements in computed diagnostic imagings. Several authors reported new treatment approaches with the marriage of radiation therapy and CT scanner (1, 3, 10, 12). They all tried to achieve a realtime positioning and immediate treatment system for optimal radiation therapy. Treatment with this dual CT-linac unit also approaches that goal, and is useful for multiple fractionated SRT for small well-circumscribed intracranial lesions.

## REFERENCES

1. Aoki, Y.; Akanuma, A.; Karasawa, K.; Sakata, K.; Nakagawa, K.; Muta, N.; Onogi, Y.; Iio, M. An integrated radiotherapy treatment system and its clinical application. *Radiat. Med.* 5:131-141; 1987.
2. Hall, E.J.; Brenner, D.J. The radiobiology of radiosurgery: Rationale for different treatment regimens for AVMs and malignancies. *Int. J. Radiat. Oncol. Biol. Phys.* 25:381-385; 1993.
3. Iwamoto, K.S.; Norman, A.; Kagan, A.R.; Wollin, M.; Olch, A.; Bellotti, J.; Ingram, M.; Skillen, R.G. The CT scanner as a therapy machine. *Radiother. Oncol.* 19:337-343; 1990.
4. Kooy, H.M.; Dunbar, S.F.; Tarbell, N.J.; Mannariono, E.; Ferarro, N.; Shusterman, S.; Bellerive, M.; Finn, L.; McDonough, C.V.; Loeffler, J.S. Adaption and verification of the relocatable Gill-Thomas-Cosman frame in stereotactic radiotherapy. *Int. J. Radiat. Oncol. Biol. Phys.* 30:685-691; 1994.
5. Laitinen, L.V.; Liljequist, B.; Fagerland, M.; Erikson, A.T. An adapter for computer tomography-guided stereotaxis. *Surg. Neurol.* 23:559-566; 1985.
6. Larson, D.A.; Bova, F.; Eisert, D.; Kline, R.; Loeffler, J.; Lutz, W.; Mehta, M.; Palta, J.; Schewe, K.; Schultz, C.; Shaw, E.; Wilson, J.F. Current radiosurgery practice: Results of an ASTRO survey. *Int. J. Radiat. Oncol. Biol. Phys.* 28:523-526; 1994.
7. Larson, D.A.; Bova, F.; Eisert, D.; Kline, R.; Loeffler, J.; Lutz, W.; Mehta, M.; Palta, J.; Schewe, K.; Schultz, C.; Shaw, E.; Wilson, J.F. Consensus statement on stereotactic radiosurgery quality improvement. *Int. J. Radiat. Oncol. Biol. Phys.* 28:527-530; 1994.
8. Larson, D.A.; Flickinger, J.C.; Loeffler, J.S. The radiobiology of radiosurgery. *Int. J. Radiat. Oncol. Biol. Phys.* 25:557-562; 1993.
9. Loeffler, J.S.; Alexander, E., III; Kooy, H.M. Stereotactic radiotherapy: Rationale, technique, and early results. In: DeSalles, A. A. F., Goetsch, S. J., eds. *Stereotactic Surgery and Radiosurgery*. Madison, WI: Medical Physics Publishing; 1993:307-320.
10. Mackie, T.R.; Holmes, T.; Swerdloff, S.; Reckwerdt, P.; Deasy, J.O.; Yang, J.; Paliwal, B.; Kinsella, T. Tomotherapy: A new concept for the delivery of dynamic conformal radiotherapy. *Med. Phys.* 20:1709-1719; 1993.
11. Phillips, M.H.; Stelzer, K.J.; Griffin, T.W.; Mayberg, M.R.; Winn, H.R. Stereotactic radiosurgery: A review and comparison of methods. *J. Clin. Oncol.* 12:1085-1099; 1994.
12. Rose, J.H.; Norman, A.; Ingram, M. First experience with radiation therapy of small brain tumors delivered by a computerized tomography scanner. *Proc. ASTRO. Int. J. Radiat. Oncol. Biol. Phys.* 30(Suppl.1):166; 1994.
13. Tokuyasu, K.; Akine, Y.; Tokita, N.; Satoh, M.; Churei, H.; Tsukiyama, I.; Egawa, S.; Oyama, H.; Nagane, M.; Shibui, S.; Nomura, K.; Iio, M.; Hara, T. Linac-based small-field radiotherapy for brain tumors. *Radiother. Oncol.* 27:55-58; 1993.